

Environmental Effects on Galaxy Evolution Based on the Sloan Digital Sky Survey

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Summary. We have constructed a large, uniform galaxy cluster catalog from the Sloan Digital Sky Survey data. By studying the morphology–cluster-centric-radius relation, we have found two characteristic environments where galaxy morphologies change dramatically, indicating there exist two different physical mechanisms responsible for the cluster galaxy evolution. We also found an unusual population of galaxies, which have spiral morphology but do not have any emission lines, indicating these spiral galaxies do not have any on-going star formation activity. More interestingly, these passive spiral galaxies preferentially exist in the cluster outskirts. Therefore, these passive spiral galaxies are likely to be a key galaxy population being transformed from blue, star-forming galaxies into red, early-type galaxies.

1 The Sloan Digital Sky Survey

The Sloan Digital Sky Survey (SDSS)[1] is both an imaging and spectroscopic survey of a quarter of the sky. Imaging part of the survey takes CCD images of the sky in five optical bands (u, g, r, i and z)[2]. The spectroscopic part of the survey observes one million galaxies. Due to its large quantity and superb quality, the SDSS provides us with an excellent data set to tackle the long standing problems on environmental effects on galaxy evolution.

2 The SDSS Cut & Enhance Galaxy Cluster Catalog

The SDSS Cut & Enhance galaxy cluster catalog (CE)[3] is one of the initial attempts to produce a cluster catalog from the SDSS imaging data. It uses generous color-cuts to eliminate fore- and background galaxies when detecting clusters. Its selection function is calculated using a Monte Carlo simulation. The accuracy of photometric redshift is $\Delta z = 0.015$ at $z < 0.3$. For a cluster catalog from the spectroscopic sample of the SDSS, see [4][5][6].

3 The Morphology-Density Relation

Using a volume limited sample of 7938 spectroscopic galaxies ($0.05 < z < 0.1$, $M_r < -20.5$), we investigated the morphology–cluster-centric-radius relation

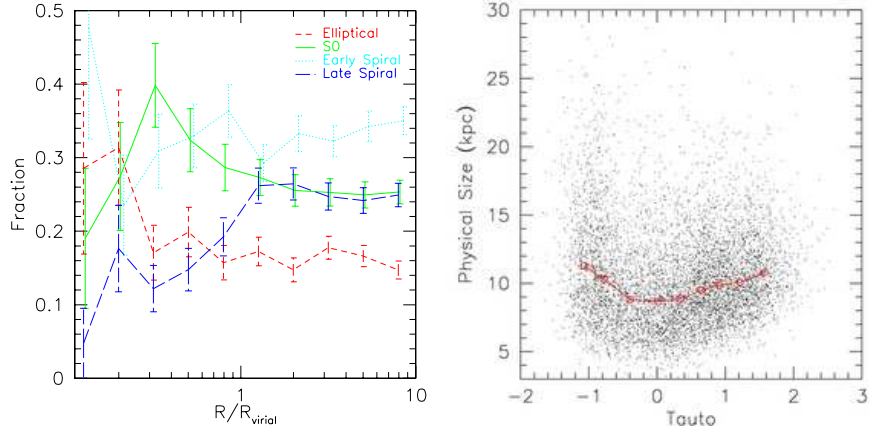


Fig. 1. (left) The morphology-radius relation. Fractions of each type of galaxies are plotted against cluster-centric-radius to the nearest cluster. The short-dashed, solid, dotted and long-dashed lines represent elliptical, S0, early-spiral and late-spiral galaxies classified with the automated method (*Tauto*), respectively.

Fig. 2. (right) Physical sizes of galaxies are plotted against *Tauto*. Petrosian 90% flux radius in *r* band is used to calculate physical sizes of galaxies. A solid line shows medians. It turns over around *Tauto* ~ 0 , corresponding to S0 population.

in the SDSS [7]. We classified galaxies using the *Tauto* method, which utilizes concentration and coarseness of galaxies (see [8] for more details of *Tauto*). We measured the distance to the nearest cluster using the C4 cluster catalog[9]. In Fig.1, morphological fractions of E, S0, Sa and Sc galaxies are shown in the short-dashed, solid, dotted and long-dashed lines as a function of cluster-centric-radius. Around $1 R_{vir}$, fractions of Sc start to decrease. Around $0.3 R_{vir}$, S0 starts to decrease and E starts to increase. These two changes imply there might be two different physical mechanisms responsible for cluster galaxy evolution. Since a physical size of S0 galaxies (*Tauto*=0) is smaller than E and Sc (*Tauto*=2 and -1) in Fig.2, the results are consistent with the hypothesis that in the cluster outskirts, stripping creates small S0 galaxies from spiral galaxies and, in the cluster cores, the merging of S0s results in a large Es.

4 The Passive Spiral Galaxies

In a similar volume limited sample of the SDSS, we have found an interesting class of galaxies with spiral morphologies (Fig. 3), and without any star formation activity (shown by the lack of emission lines in the spectrum; Fig. 4). These galaxies are called “passive spiral galaxies”, and interesting since

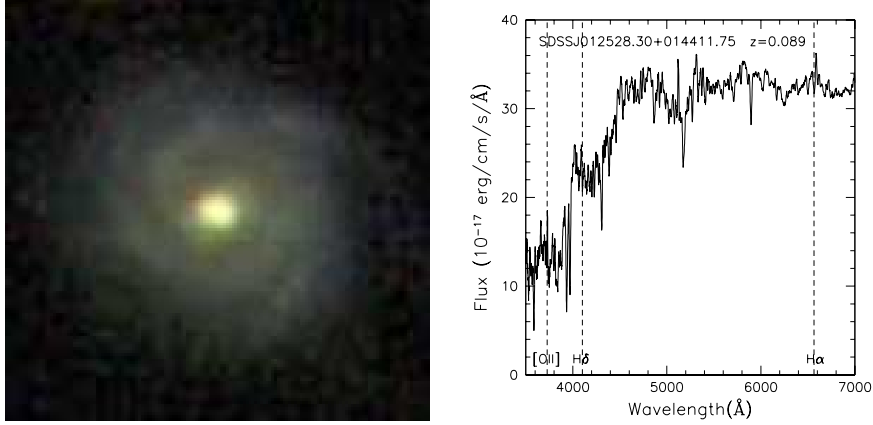


Fig. 3. (left) An example image of a passive spiral galaxy. The image is a composite of SDSS g, r and i bands, showing $30'' \times 30''$ area of the sky with its north up. Discs and spiral arm structures are recognized.

Fig. 4. (right) An example restframe spectrum of the passive spiral galaxy. The spectrum is shifted to restframe and smoothed using a 10\AA box. The image is shown in Fig. 3.

they are against currently favored galaxy formation models in which star-formation is sustained by the density waves. Using a volume-limited sample ($0.05 < z < 0.1$ and $Mr^* < -20.5$; 25813 galaxies) of the SDSS data, we found 73 ($0.28 \pm 0.03\%$) passive spiral galaxies and studied their environments. It is found that passive spiral galaxies exist in a local galaxy density of $1\text{--}2 \text{ Mpc}^{-2}$ and have a $1\text{--}10$ cluster-centric virial radius (Figs. 5 and 6; [10]). In other words, passive spirals preferentially exist in the cluster infalling regions. This is the first direct evidence to connect the origin of passive spiral galaxies to cluster related physical mechanisms. These characteristic environments coincide with a previously reported environment where the galaxy star-formation rate suddenly declines[11] and the so-called morphology-density relation turns (See Section 3). It is likely that the same physical mechanism is responsible for all of these observational results in the cluster infalling regions. The existence of passive spiral galaxies suggests that a physical mechanism that works calmly (e.g., gas stripping) is preferred to dynamical origins such as major merger/interaction since such a mechanism would destroy the spiral-arm structures. Passive spiral galaxies are likely to be a key galaxy population in transition between red, early-type galaxies in low-redshift clusters and blue, spiral galaxies more numerous in higher-redshift clusters.

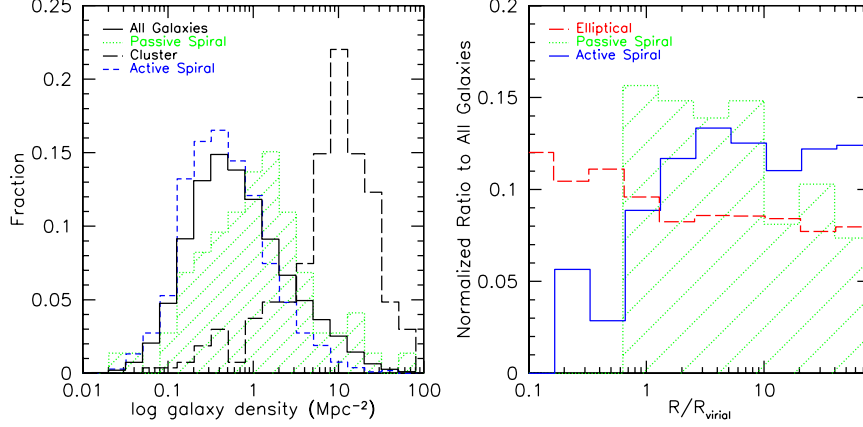


Fig. 5. (left) The density distribution of passive spiral galaxies (hashed region) and all galaxies (solid line) in a volume limited sample. Local galaxy density is measured based on the distance to the 5th nearest galaxy within ± 3000 km/s. A Kolomogorov-Smirnov test shows distributions of passive spirals and all galaxies are significantly different. A long dashed line shows the distribution of cluster galaxies. A short dashed line shows that of active spiral galaxies. Both of them are statistically different from that of passive spirals.

Fig. 6. (right) The distribution of passive spiral galaxies as a function of cluster-centric-radius. The solid, dashed and dotted lines show the distributions of passive spiral, elliptical and active spiral galaxies, respectively. The distributions are relative to that of all galaxies in the volume limited sample and normalized to be unity for clarity. The cluster-centric-radius is measured as a distance to a nearest C4 cluster[9] within ± 3000 km/s, and normalized by virial radius [12].

5 Conclusions

We have constructed a large, uniform galaxy cluster catalog from the SDSS data in order to investigate physical mechanisms responsible for the cluster galaxy evolution. By revealing the morphology–cluster-centric-radius relation with the largest statistics to date, we have found two characteristic environments where galaxy morphology changes dramatically, suggesting the existence of two different physical mechanisms in the cluster regions. In addition, we have found unusual galaxies with spiral morphology but without any emission lines. More interestingly, we found that these passive spiral galaxies preferentially exist in the cluster infalling regions, indicating that they are likely to be transition objects between field star-forming spirals and red, cluster early-type galaxies due to the environmental effects in the cluster outskirts.

References

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